Mr Glahn
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DEVELOPMENT OF LFM MAX/MIN AND 3-HOURLY TEMPERATURE EQUATIONS FOR THE COOL SEASON

J. Paul Dallavalle, Gary M. Carter, and Albert L. Forst

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I. INTRODUCTION

Since June 1978 the Techniques Development Laboratory has used the Limited-Area Fine Mesh (LFM-II) model (NWS, 1977) to produce "early Model Output Statistics (MOS) maximum/minimum (max/min) temperature forecasts and 3-h surface temperature guidance valid every 3 hours from 6 to 51 hours after 0000 or 1200 GMT (NWS, 1978a). Prognoses are available for approximately 232 stations in the conterminous United States. Linear regression equations, derived from a combination of LFM model data, surface observations, and climatic terms, are used to make the forecasts. Additional details about the development of the warm season (April-September) early guidance equations may also be found in Carter et al. (1978).

We recently completed the derivation of early guidance equations to predict the max/min and 3-h temperatures during the cool season (October-March). In fact, these equations are now being used in day-to-day operations. For the first time, we screened the observed snow cover at 1200 GMT as a potential predictor for the max/min and 3-hourly prediction equations. This paper describes the development of the cool season early guidance temperature equations. We will present statistics obtained on the dependent sample and give details explaining the early guidance system.

II. PROCEDURE

The MOS technique of developing linear regression equations to forecast meteorological quantities has been described in detail (Glahn and Lowry, 1972). Briefly speaking, we may define it as a system of correlating output from numerical models, station observations, and various climatic quantities with a meteorological parameter observed at a particular location. In the case of temperature forecasting, we interpolate output from a numerical model such as the LFM to the station of interest. As additional forecasting information, we also consider the first two harmonics of the day of the year (climatic terms) and the station observations during the earlier forecast projections when persistence is often important. The model output, climatic terms, and station observations form a set of predictors which may be related to the observed calendar day max/min or surface temperature (predictand). After our data base is obtained, we use a forward stepwise screening technique to derive a linear regression, single-station equation relating the predictand (max, min, or a surface temperature) to the station predictors. A predictor is chosen in an equation on the basis of adding the most reduction of variance to the relation when combined with previously chosen predictors. In this particular derivation we continued the screening until no predictor added more than .01% to the total reduction of variance or until a 10-term equation was obtained. All of the cool season equations contain

10 terms. The equations are of the form:

$$\hat{T} = a_0 + a_1X_1 + a_2X_2 + \ldots + a_{10}X_{10} ,$$

where $\hat{T}$ is the predicted temperature, a_0 is the regression constant, the a_i's $(i=1,2,\ldots,10)$ are the regression coefficients, and the X_i's are the predictors.

In our current temperature prediction system, we needed separate equations to predict the calendar day max and min, and the 3-h surface temperature. This posed a problem, however, since we did not want a temperature forecast for a specific hour to be greater (less) than the max (min) guidance for a calendar day. In short, consistency among the early guidance forecasts was a concern. We attempted to deal with this dilemma by combining the calendar day max (or min) temperature with a number of the 3-h temperature observations into a set of temperature predictands. Thus, when the equations were developed for one predictand set, all equations were derived simultaneously. The result was a set of equations that used the same 10 predictors, but with different regression coefficients. Hence, the equations are distinct and do produce different temperature forecasts. While the likelihood of consistent forecasts is enhanced by this method, consistency is not guaranteed.

Fig. 1 illustrates the grouping of predictands into distinct sets. For instance, for 0000 GMT cycle equations, we associated today's max (calendar-day) with the surface temperatures valid every 3 hours from 6 to 27 hours after 0000 GMT. Equations for these nine predictands were derived simultaneously. Likewise, tomorrow's min (which usually verifies approximately 36 hours after 0000 GMT) was combined with the temperatures at 27 through 39 hours after 0000 GMT. The calendar day max for tomorrow was matched with the surface temperatures valid every 3 hours at 39 through 51 hours after 0000 GMT. Finally, the equation to predict the min for the day after tomorrow was derived separately. The method for deriving 1200 GMT equations was analogous except that the 24-h projection corresponded roughly to the min; the 36-h projection, approximately to the max, and so forth.

In Table 1 we've listed the potential model predictors used in deriving the 0000 GMT cycle equations. The 3-h sets are those defined in Fig. 1. We screened heights, thicknesses, lower- and mid-tropospheric temperatures and dew points, lower- and mid-tropospheric winds, the wind-derived relative vorticity at 850 mb, the geostrophic relative vorticity at 500 mb, vertical velocities, temperature differences between layers (stabilities), the boundary layer and mean relative humidities, the precipitable water, the temperature advection at 850 mb, the geostrophic vorticity advection at 500 mb, and the boundary layer wind divergence. In developing the equations for a particular predictand set, we usually included several different model projections of the forecast fields valid near the time of the predictands. Note that in forecasting today's max, we also screened several model fields that represented initial conditions. Most of the model output was smoothed by a five-point space smoother in order to reduce model noise. However, as the predictand projection increased, more fields were smoothed by a nine-point filter. For the last projection, essentially a 60-h forecast of the min, we employed a 25-point filter on some of the fields because the model forecasts were only valid to 48 hours after the initial model time. Though it is not indicated in Table 1, we also screened the first and second harmonics of the day of the year as climatic predictors for all predictands. The predictors for the 1200 GMT cycle were analogous except that the projections referred to hours after 1200 GMT.

For the first two predictand sets, we added station observations as potential predictors. Quantities such as surface temperature, dew point, sky cover, surface u- and v-winds, surface wind speed, ceiling, the previous maximum or minimum, and the observed snow cover at 1200 GMT were included. Table 2 gives a detailed listing of these predictors for both the 0000 GMT and 1200 GMT cycle development. When we derived equations for the first two predictand groups, we developed one set that included observations (primary equations) and one that used only model fields and the climatic terms (backup equations). In operations we want to use the primary equation for each station, but if the necessary observed predictors are missing, we can revert to the backup equation and still produce a forecast.

Note that the ceiling and snow cover observations were both used as binary predictors. In fact, this was the first time that we had included snow cover as a predictor in the MOS temperature equations. As a binary predictor was assigned the value of one if the observation did not exceed the cutoff value. Otherwise, the predictor was set equal to zero. When we screened ceiling as a binary predictor, the cutoff value was 10000 feet. For snow cover, limits of a trace, 1, 2, and 5 inches were used. The 1200 GMT snow cover report was screened because in an operational environment, a station is required to report the snow cover only at 1200 GMT. More details on the choice of snow cover as a binary predictor may be found in Dallavalle and Carter (1978).

We have archived LFM model forecasts out to 24 hours since October 1, 1972. However, forecasts to 36 hours have been available only since April 2, 1975 while forecasts to 48 hours have been archived since February 1, 1976. As a result of these inconsistencies, we had a problem with our seasonal stratification. Previous results (Hammons et al., 1976) had indicated the benefits of deriving equations for 3-month seasons. Due to the data limitations, however, we could only derive 3-month seasonal equations for the first predictor set. Thus, we developed fall (October-December) and winter (January-March) equations for the first predictand set and cool season (October-March) equations for the other three predictand sets. Table 3 summarizes the data used in the development of the 0000 GMT equations. The tabulations are similar for 1200 GMT. Approximately 1 season in each sample is actually composed of LFM-II (NWS, 1977a) data, because on September 1977 the National Meteorological Center converted the LFM model to a finer mesh.

III. RESULTS

We developed early guidance max/min and 3-h temperature equations for 232 stations in the conterminous United States (Table 4). Because of missing surface observations when certain stations were closed, it was not always possible to derive primary and backup equations for each projection. Similarly, a few stations closed completely at some time during our period of record, so that occasionally we could not derive any equation for a particular station and projection. In Table 5 we have listed stations and projections for which no forecasts are made during the cool season.

The standard errors of estimate for both cycles for the max/min equations and the 3-h surface temperature equations are given in Figs. 2 and 3, respectively. The open symbols denote the statistics for the primary forecast equations while the darkened symbols indicate statistics for the backup equations. Note that the use of surface observations as predictors for the surface temperature decreased the standard error by only 0.1° to 0.2°F after the 15-h projection. The greatest improvement occurred for the 6-h projection when the latest observed surface temperature was always the leading predictor in the forecast equation. In other words, persistence was very important in making what amounted to a 3-h forecast. The influence of persistence decreased dramatically after this projection. The standard errors for the surface temperature generally tended to increase with time although there were relative minima at 0000 and 1500 GMT. The reason for this is not clear. Since these hours correspond approximately to a short interval after sunset and sunrise, respectively, perhaps the smaller variation in temperature at these times makes forecasts for the two periods more accurate.

In regard to the max/min (Fig. 2), it is generally easier to forecast the max rather than the min during the cool season. It has been our observation that the max is more influenced during the cool season by synoptic-scale features which the numerical models forecast well. On the other hand, the min is more variable, being subject to drainage winds, low-level cloudiness and other small-scale features that the models often do not predict. In our dependent sample, the standard error for the min was always greater than that for the max at the same projection. We have seen this before (Hammons et al., 1976). The use of surface observations as predictors in the first two max/min projections only improved the standard errors by 0.1 to 0.2°F. This certainly was not as great as in our 3-month derivations (Hammons, op. cit.), but the method of derivation in this case tended to preclude the influence of the previous max or min. As noted above, the surface temperature observed 3 hours after 0000 or 1200 GMT was always chosen as the first predictor in the set 1 equations. Moreover, we did not use the previous observed max or min in these equations which also weakened the effect of observations in forecasting the calendar day max or min.

The binary snow cover predictor was chosen quite frequently in the set 1 equations for the winter season. For the fall season equations, this particular predictor was chosen about a third as frequently. In Fig. 4 we have indicated those stations that use snow cover during the winter as a predictor for today's max (0000 GMT cycle). Fig. 5 gives similar information for tomorrow's min (1200 GMT cycle). In general, stations across the northern tier of states and in the Rocky Mountain region have observed snow cover as a predictor. Note that this term was chosen less frequently for the 24-h max than for the 24-h min, especially in the northeastern and northwestern United States. This effect may be because during the 0000 GMT cycle we are using an observation of snow cover that is already 12 hours old. The snow cover as a predictor for the 24-h max was pretty much restricted to the Plains region between the Rocky and Appalachian Mountains.

The five most important predictors for the 0000 GMT and 1200 GMT equations are given in Tables 6 and 7, respectively. This list was determined by both the frequency and order of selection. Remember, however, that we derived these equations in sets. Thus, a specific predictor may have been important for one predictand, (e.g., the temperature at 6 hours after 0000 GMT), while being relatively unimportant in predicting another parameter, such as today's max. Generally, the same predictors were important in both cycles for all projections. When station observations were screened in the development work (sets 1 and 2), the observed surface temperature at the station was one of the most important predictors. Obviously, persistence is a major factor in temperature forecasting. When observations were not used as predictors for the first two equation sets, the LFM surface temperature generally became an important predictor. This term represents the model-analyzed surface temperature field at the initial data time. This quantity also is a type of persistence, so it replaces specific observations when unavailable. For all projections, the forecast of the 850- to 1000-mb thickness field was an extremely important predictor. This variable gives some indication of the temperature structure in the lower troposphere. For the set 1 equations, generally the forecast of the dew point at 850 or 1000 mb or the mean relative humidity was chosen as a major predictor to indicate low-level cloudiness. Likewise, for nearly all equation sets, another lower-tropospheric temperature field (for example, the 1000- or 850-mb temperature or the boundary layer potential temperature) was a commonly chosen predictor. Finally, the cosine of the day of the year or of twice the day of the year was used prominently in nearly all equation sets as an indication of seasonal trends. In fact, for the 0000 GMT equations, the forecast of the day after tomorrow's min had three climatic terms as leading predictors.

The equation to predict today's max at Omaha, Nebraska from 0000 GMT model data during the winter season is given in Table 8. Note the importance of the observed surface temperature at 0300 GMT and the two forecasts of the 850- to 1000-mb thickness. The cosine day of the year also is used in this equation. In addition, the reported snow cover from yesterday's 1200 GMT observation is a binary predictor. In this instance, if the snow cover is a trace or less, then the binary predictor is set equal to one and approximately $4^{\circ}F$ is added to the forecast. If the snow cover is an inch or more, nothing is added to the forecast. From another point of view, if Omaha reports that snow exceeds a trace, then $4^{o}F$ is subtracted from the max forecast derived solely from model parameters, the observed surface temperature, and the cosine day of the year.

IV. OPERATIONAL DETAILS

In operations, forecasts from these new cool season equations are based on LFM-II output. The max/min guidance and the 3-hourly temperature forecasts are given in the early FOUS12 teletypewriter message for 232 stations (Table 4). The max/min forecasts are available in this message only out to the 48-h projection. The 3-hourly surface temperature forecasts are listed for the projections from 6 to 51 hours after the initial model time (0000 or 1200 GMT). Recall, in our development, we derived two equations for the 27- and 39-h projection. The guidance that appears on the early FOUS12 message for these projections is the average of the forecasts produced by the two equations. The max/min forecasts for all four projections and all 232 stations appear in the early FOUS22 teletypewriter message. No 3-hourly guidance appears on this message.

The early guidance max/min temperature forecasts for all four projections also appear on a computer-produced four panel chart (labeled "TDLFM") available on the National Facsimile (NAFAX), National Aviation and Meteorological Facsimile (NAMFAX), and Digital Facsimile (DACOM) networks. Computer-drawn isotherms at 10-degree Fahrenheit intervals are determined by the MOS forecasts at 228 stations and by "perfect prog" (Klein and Lewis, 1970) forecasts at 16 stations. However, due to a lack of space, the forecasts are plotted only at 135 MOS stations and the 16 perfect prog stations. More details on the teletype message and the facsimile chart may be found in NWS (1978a and 1978b).

As we indicated earlier, when we developed these temperature forecast equations we tried to avoid inconsistencies between the max or min and the 3-hourly surface temperature forecasts. To reiterate, in deriving equations valid at one station, we required the same predictors to be chosen for all equations of a particular predictand set. Since the regression coefficients differ, however, the equations for the max (or min) and the corresponding 3-hourly surface temperatures are distinct, and consistency among the resulting forecasts is not guaranteed.

In Table 9 we have presented a sample FOUS12 message for Columbus, Ohio (CMH) for 0000 GMT on December 8, 1977. The forecasts in the message were produced from developmental data. As Figs. 6 through 8 indicate, the period in question was dominated by a rapidly moving low pressure area. This system began as a lee-side cyclone, moved through Oklahoma and then recurved northward through the Ohio River valley and across Lake Huron. While the low itself intensified little, the strong anticyclone pushing southward out of the Northwest

Territory strengthened the pressure gradient and was associated with a massive cold air outbreak in the central part of the United States. An investigation of the LFM progs run from 0000 GMT data on December 8 indicated that the model forecast the situation well in advance.

Please note that the sample message in Table 9 was never transmitted; rather, it exemplifies some possible problems with the new early guidance package. Two lines were added to the message to indicate the observed temperatures (MX/MN OBS and OBS); an "M" denotes a missing value. Naturally, these lines are not on the operational bulletin. Several points are clear. First, today's max forecast (24°F) is much less than the temperature forecasts at 24 or 27 hours after 0000 GMT. Though equations for these projections use the same predictors, the forecasts in this case are anything but consistent. Secondly, at first glance, the forecast for tomorrow's max (35°F) looks horrible, but it actually is pretty good. Remember, the objective max and min forecasts are valid for a local calendar day and not a 12-h period. In this situation, the max occurred a little after midnight. Third, the forecast for tomorrow's min (14°F) is higher than the temperature forecast at 51 hours after 0000 GMT. This is more understandable, since the equations for these two projections use different predictors. Moreover, the same min forecast is much less than the forecast temperature at 1200 or 1500 GMT for that day. Obviously, neither the max nor the min forecasts are derived from the 3-hourly forecast values. Overall, the 3-hourly temperature forecasts captured the anomalous diurnal temperature trace, particularly during the evening of December 8. The daytime cooling that occurred on December 9 was also predicted, though the magnitude was drastically underforecast.

What should field forecasters do if confronted with temperature guidance like this? Certainly, they should realize that contradictions in the forecast do occur and that the forecaster's meteorological reasoning plays an important part in interpreting the objective guidance. Perhaps, in cases of nocturnal warming and daytime cooling the early guidance will show the temperature trend but will miss the absolute values, particularly during extreme instances of warming or cooling. Additionally, the early max or min forecasts for these cases may tend to be too conservative because the max (or min) forecast equations were derived simultaneously with temperature equations for nearby hours. Since nocturnal warming is an anomalous situation, the early max/min forecasts may begrudgingly, if at all, show these extremes. There is another complication here since the forecast equation for tomorrow's min (calendar day) from 0000 GMT was derived with equations for the temperatures at 27, 30, 33, 36, and 39 hours after 0000 GMT. If the early morning temperatures are warm and the temperature then begins to fall rapidly in the later afternoon or evening, there seems to be an inherent contradiction in the way we stratified the equations. At this point, it is difficult to say whether these rapidly changing situations will be handled properly by the early guidance.

Of course, this is only one example obtained from developmental data. What will happen this winter remains to be seen. It may be that in a situation where the diurnal temperature curve is out of phase, the forecaster might follow the 3-h guidance for the trend. The early guidance max/min should then be treated with discretion. We will need to monitor the guidance closely this winter to determine if these comments remain valid.

V. CONCLUSIONS

The 3-h temperature guidance and early max/min guidance are now based on equations derived from the LFM model. Operationally, LFM-II model data is used as input to these equations. Continuing verification of the operational product will indicate its usefulness. We may find that redevelopment of the equations is necessary. In particular, we may eventually develop only 3-h temperature forecast equations, and the max/min forecasts for 12-h periods would be derived by fitting a curve to the 3-h forecasts and then picking a max or min. We will also see this winter how well the snow cover predictor corrects for biases in the max/min forecasts.

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Table 1. Potential predictors used to derive the MOS cool season early guidance (LFM-based) temperature prediction equations for the 0000 GMT forecast cycle. The stars indicate the field was smoothed by five points (*), nine points (**) or 25 points (***).

LFM Field	Today's Max 3-hr Set #1	Tomrw's Min 3-hr Set #2	Tomrw's Max 3-hr Set #3	Day after Tomrw's Min
1000-mb height	12*,24*	24*,30*,36*	36**,42**,48**	48**,48***
850-mb height	12,24	24,30,36	36,42,48	48*,48**
500-mb height	12,24	24,30,36	36,42,48	36*,48*
500-1000 mb thickness	0,6,12,18,24	24,30,36	36,42,48	48*
850-1000 mb thickness	0,6,12,18,24	24,30,36	36,42,48*	48*,48**
500-850 mb thickness	0,6,12,18,24	24,30,36	36,42,48*	48*
Sfc temp	0	0	-	-
1000-mb temp	12*,24*	24*,36*	36**,48**	48**,48***
850-mb temp	0,6,12,18,24	0,24*,30*,36*	36*,42*,48*	48*,48**
700-mb temp	0,12,24	24,30,36	36*,42*,48*	48*,48**
Bnd lyr pot temp	6,12,18*,24	24*,30*,36*	36*,42*,48*,48**	48*,48**
Bnd lyr u wind	6,12,18*,24*	24*,30*,36*	36*,42*,48*	48*,48**
Bnd lyr v wind	6,12,18*,24*	24*,30*,36*	36*,42*,48*	48*,48**
Bnd lyr wnd spd	6,12,18*,24*	24*,30*,36*	36*,42*,48*	48*,48**
850-mb u wind	6,12,18*,24*	24*,30*,36*	36*,42*,48*	48**
850-mb v wind	6,12,18*,24*	24*,30*,36*	36*,42*,48*	48**
700-mb u wind	12,24*	24*,36*	36*,48*	48**
700-mb v wind	12,24*	24*,36*	36*,48*	48**
850-mb rel vort	6*,12*,18*,24*	30**,36**	42**,48**	48**
500-mb rel vort	12*,24*	30**,36**	42**,48**	48**
850-mb vert vel	12*,24*	36*	48**	48***
700-mb vert vel	12*,24*	30*,36*	42**,48**	48***
700-1000 mb temp dif	12,24	36*	48*	48**
500-850 mb temp dif	12,24	30*,36*	42*,48*	48**
Bnd lyr rel hum	0*,6*,12*,18*,24*	24*,30*,36*	36**,42**,48**	48***
Mean rel hum	6*,12*,18*,24*	24*,30*,36*	36**,42**,48**	48***
Precip water	6*,12*,18*,24*	30*,36*	42**,48**	48***
1000-mb dew pt	6*,12*,18*,24*	30*,36*	42*,48*	48**,48***
850-mb dew pt	12*,24*	30*,36*	42*,48*	48**
700-mb dew pt	12*,24*	30*,36*	42*,48*	48**
Bnd lyr wnd divg	6*,12*,18*,24*	30*,36*	42**,48**	48***
850-mb temp adv	12*,24*	30*,36*	42**,48**	48***
500-mb vort adv	12*,24*	30*,36*	42**,48***	48***

Table 2. Potential observed predictors used to derive the MOS cool season early guidance (LFM-based) temperature prediction equations.

Element	0000 GMT Cycle		1200 GMT Cycle	
	Today's Max 3-hr Set #1	Tomrw's Min 3-hr Set #2	Tomrw's Min 3-hr Set #1	Tomrw's Max 3-hr Set #2
Sfc temperature	0300 0000 2100 (Yesterday)	0300 0000	1500 1200	1500 1200
Sfc dew point	0300	0300	1500	1500
Sky cover	0300	0300	1500	1500
Sfc u wind	0300	0300	1500	1500
Sfc v wind	0300	0300	1500	1500
Sfc wind speed	0300	0300	1500	1500
Ceiling height (Binary: cutoff of 10000 feet)	0300	0300	1500	1500
Previous maximum temp	--	--	--	1200
Previous minimum temp	--	0000	--	--
Snow cover (Binary: cutoff of trace, 1 inch, 2 inches, 5 inches)	1200 (Yesterday)	--	1200	1200

Table 3. Number of seasons of archived 0000 GMT cycle forecasts from the LFM model available for the development of MOS early guidance temperature prediction equations.

Season	Today's Max 3-hr Set #1	Tomrw's Min 3-hr Set #2	Tomrw's Max Day after Tomrw's Min 3-hr Set #3
Spring (April-June)	5 (1973-77)	--	--
Summer (July-September)	5 (1973-77)	--	--
Warm (April-September)	--	3 (1975-77)	2 (1976-77)
Fall (October-December)	6 (1972-77)	--	--
Winter (January-March)	6 (1973-78)	--	--
Cool (October-March)	--	3 (1975-78)	2 (1976-78)

Table 4. The 232 stations for which early guidance max/min and 3-h temperature equations were derived. Some stations do not have forecast equations for all projections.

Birmingham AL	Tallahassee FL	Shreveport LA	Lovelock NV	Burns OR	Lubbock TX
Huntsville AL	Tampa FL	Bangor ME	Reno NV	Eugene OR	Lufkin TX
Mobile AL	West Palm Beach FL	Caribou ME	Tonopah NV	Medford OR	Midland TX
Montgomery AL	Athens GA	Portland ME	Winnemucca NV	North Bend OR	San Angelo TX
Flagstaff AZ	Atlanta, GA	Baltimore MD	Concord NH	Pendleton OR	San Antonio TX
Phoenix AZ	Augusta GA	Boston MA	Atlantic City NJ	Portland OR	Victoria TX
Tucson AZ	Macon GA	Alpena MI	Newark NJ	Redmond OR	Waco TX
Winslow AZ	Savannah GA	Detroit MI	Albuquerque NM	Salem OR	Wichita Falls TX
Yuma AZ	Boise ID	Flint MI	Farmington NM	Allentown PA	Bryce Canyon UT
Fort Smith AR	Pocatello ID	Grand Rapids MI	Truth or Consequences NM	Bradford PA	Cedar City UT
Little Rock AR	Chicago (Midway) IL	Houghton Lake MI	Tucumcari NM	Erie PA	Salt Lake City UT
Arcata CA	Chicago (O'Hare) IL	Lansing MI	Albany NY	Harrisburg PA	Wendover UT
Bakersfield CA	Moline IL	Muskegon MI	Binghamton NY	Philadelphia PA	Burlington VT
Daggett CA	Peoria IL	Sault Ste. Marie MI	Buffalo NY	Pittsburgh, PA	Lynchburg VA
Fresno CA	Rockford IL	Traverse City MI	Massena NY	Scranton PA	Norfolk VA
Long Beach CA	Springfield IL	Duluth MN	New York (Kennedy) NY	Williamsport PA	Richmond VA
Los Angeles CA	Evansville IN	International Falls MN	New York (LaGuardia) NY	Providence RI	Roanoke VA
Oakland CA	Fort Wayne IN	Minneapolis MN	Rochester NY	Charleston SC	Washington-Dulles VA
Red Bluff CA	Indianapolis IN	Rochester MN	Syracuse NY	Columbia SC*	Olympia WA
Sacramento CA	South Bend IN	Jackson MS	Asheville NC	Greenville SC	Quillayute, WA
San Diego CA	Burlington IA	Meridian MS	Cape Hatteras NC	Aberdeen SD	Seattle-Tacoma WA
San Francisco CA	Des Moines IA	Columbia MO	Charlotte NC	Huron SD	Spokane WA
Santa Maria CA	Dubuque IA	Kansas City MO	Greensboro NC	Pierre SD	Yakima WA
Stockton CA	Mason City IA	St. Louis MO	Raleigh-Durham NC	Rapid City SD	Beckley WV
Colorado Springs CO	Sioux City IA	Springfield MO	Wilmington NC	Sioux Falls SD	Charleston WV
Denver CO	Waterloo IA	Billings MT	Bismarck ND	Bristol TN	Elkins WV
Grand Junction CO	Concordia KS	Glasgow MT	Fargo ND	Chattanooga TN	Huntington WV
Pueblo CO	Dodge City KS	Great Falls MT	Minot ND	Knoxville TN	Eau Claire WI
Bridgeport CT	Goodland KS	Havre MT	Williston ND	Memphis TN	Green Bay WI
Hartford CT	Russell KS	Helena MT	Akron-Canton OH	Nashville TN	Lacross WI
Wilmington DE	Topeka KS	Kalispell MT	Cincinnati OH	Abilene TX	Madison WI
Washington DC	Wichita KS	Missoula MT	Cleveland OH	Amarillo TX	Milwaukee WI
Daytona Beach FL	Lexington KY	Grand Island NE	Columbus OH	Austin TX	Casper WY
Fort Myers FL	Louisville KY	North Platte NE	Dayton OH	Brownsville TX	Cheyenne WY
Jacksonville FL	Alexandria LA	Omaha NE	Toledo OH	Corpus Christi TX	Lander WY
Key West FL	Baton Rouge LA	Scottsbluff NE	Youngstown OH	Del Rio TX	Rock Springs WY
Miami FL	Boothville LA	Elko NV	Oklahoma City OK	El Paso TX	Sheridan WY
Orlando FL	Lake Charles LA	Ely NV	Tulsa OK	Fort Worth TX	
Pensacola FL	New Orleans LA	Las Vegas NV	Astoria OR	Houston TX	

Table 5. Station and projections for which no forecasts are made during the cool season.

STATION	0000 GMT CYCLE	1200 GMT CYCLE
Santa Maria CA	6-, 9-, 12-, 30-, 33-, 36-h temperatures	18-, 21-, 24-, 42-, 45-, 48-h temperatures
Boothville LA	30-, 33-, 45-h temperatures	42-, 45-h temperatures
Burns OR	6-, 9-, 30-, 33-h temperatures	18-, 21-, 42-, 45-h temperatures
Bryce Canyon UT	42-, 45-, 48-, 51-h temperatures 48-h maximum	42-, 45-, 48-, 51-h temperatures 48-h minimum, 60-h maximum
Wendover UT	42-, 45-, 48-, 51-h temperatures 48-h maximum, 60-h minimum	42-, 45-, 48-, 51-h temperatures 48-h minimum, 60-h maximum

Table 6. Five most important predictors for the cool season 0000 GMT early temperature forecast equations. Ranking is based both on the order and frequency of selection in the equation development. Note that set 1 equations include today's max; set 2, tomorrow's min; and set 3, tomorrow's max.

Set 1 - fall (with obs)	Set 1 - fall (no obs)	Set 1 - winter (with obs)	Set 1 - winter (no obs)
Obs sfc temp	LFM 850-1000 mb th	Obs sfc temp	LFM 850-1000 mb th
LFM 850-1000 mb th	LFM sfc temp	LFM 850-1000 mb th	LFM sfc temp
LFM 850-mb dew pt	LFM BL pot temp	LFM 850-mb dew pt	LFM BL pot temp
Cosine day of year	LFM 850-mb dew pt	LFM BL pot temp	LFM 1000-mb temp
LFM 1000-mb dew pt	LFM 1000-mb dew pt	Cosine twice day of year	LFM 1000-mb dew pt
Set 2 (with obs)	**Set 2 (no obs)**	**Set 3**	**Day after tomorrow's min**
LFM 850-1000 mb th	LFM 850-1000 mb th	LFM 850-1000 mb th	LFM 850-1000 mb th
Cosine day of year	LFM sfc temp	LFM BL pot temp	Cosine day of year
Obs sfc temp	Cosine day of year	Cosine day of year	Cosine twice day of year
LFM BL pot temp	LFM BL pot temp	Cosine twice day of year	Sine twice day of year
LFM BL wind speed	LFM BL wind speed	LFM 1000-mb temp	LFM BL v wind

Table 7. Five most important predictors for the cool season 1200 GMT early temperature forecast equations. Ranking is based both on the order and frequency of selection in the equation development. Note that set 1 equations include tomorrow's min; set 2, tomorrow's max; and set 3, day after tomorrow's min.

Set 1 - fall (with obs)	Set 1 - fall (no obs)	Set 1 - winter (with obs)	Set 1 - winter (no obs)
Obs sfc temp	LFM 850-1000 mb th	Obs sfc temp	LFM 850-1000 mb th
LFM 850-1000 mb th	Cosine day of year	LFM 850-1000 mb th	LFM mean rel hum
LFM 850-mb dew pt	LFM mean rel hum	Cosine twice day of year	LFM sfc temp
Cosine day of year	LFM 850-mb temp	LFM mean rel hum	Cosine twice day of year
LFM 850-mb temp	LFM 850-mb dew pt	Cosine day of year	LFM BL pot temp
Set 2 (with obs)	**Set 2 (no obs)**	**Set 3**	**Day after tomorrow's max**
LFM 850-1000 mb th	LFM 850-mb temp	LFM 850-1000 mb th	LFM 850-1000 mb th
Obs sfc temp	LFM 850-1000 mb th	Cosine day of year	Cosine day of year
LFM 850-mb temp	Cosine day of year	LFM BL pot temp	LFM 1000-mb temp
Cosine day of year	LFM mean rel hum	LFM 850-mb temp	Cosine twice day of year
Cosine twice day of year	Cosine twice day of year	Cosine twice day of year	LFM 850-mb temp

Table 8. Sample equation to predict today's max (^{o}F) at Omaha, Nebraska from 0000 GMT model data. Development of this winter season (January-March) equation was based on 6 years of data (1973-78). The equation was derived simultaneously with expressions to forecast the hourly temperature every 3 hours from 6 to 27 hours after 0000 GMT.

Predictor	Regression Coefficient	Cumulative Reduction Of Variance
0300 GMT Observed surface temp (^{o}F)	0.142	0.625
24-hour LFM 850-1000 mb thickness (m)	0.049	0.836
12-hour LFM 850-1000 mb thickness (m)	0.178	0.848
Cosine day of year	-7.409	0.862
12-hour LFM mean rel humidity (%)	0.005	0.866
Yesterday's 1200 GMT observed snow cover (binary predictor: 1 if < 1 inch; zero otherwise)	4.042	0.877
24-hour LFM bndry layer rel humidity (%)	-0.127	0.889
12-hour LFM bndry layer wind speed (m sec^{-1})	0.091	0.890
18-hour LFM 1000-mb dew point (^{o}K)	0.101	0.891
18-hour LFM bndry layer v wind (m sec^{-1})	0.141	0.893
Initial constant = -278.3^{o}F	Standard error of estimate = 5.06^{o}F	

Table 9. Sample FOUS12 message (early guidance) for Columbus, Ohio. The message was composed from 0000 GMT developmental data on December 8, 1977. The lines labeled "MX/MN OBS" and "OBS" contain the actual observed max/min and surface temperatures, respectively, and do not appear in an actual message.

HDNG FOUS12 MOS FCSTS EARLY GUIDANCE 12/08/77 0000 GMT

DATE/GMT	08/06		08/12		08/18		09/00		09/06		09/12		09/18		10/00	
CMH POP06								.								
POP12																
QPF06								.								
QPF24																
POPT								.								
POSH																
MX/MN								24				14				35
MN/MN OBS								31				1				31
TEMP	11	11	14	18	23	27	30	33	33	30	28	24	21	16	13	10
OBS	11	11	11	14	21	24	M	M	32	31	22	17	13	6	2	2
WIND								.								
CLDS																
CIG								.								
VIS																
C/V								.								

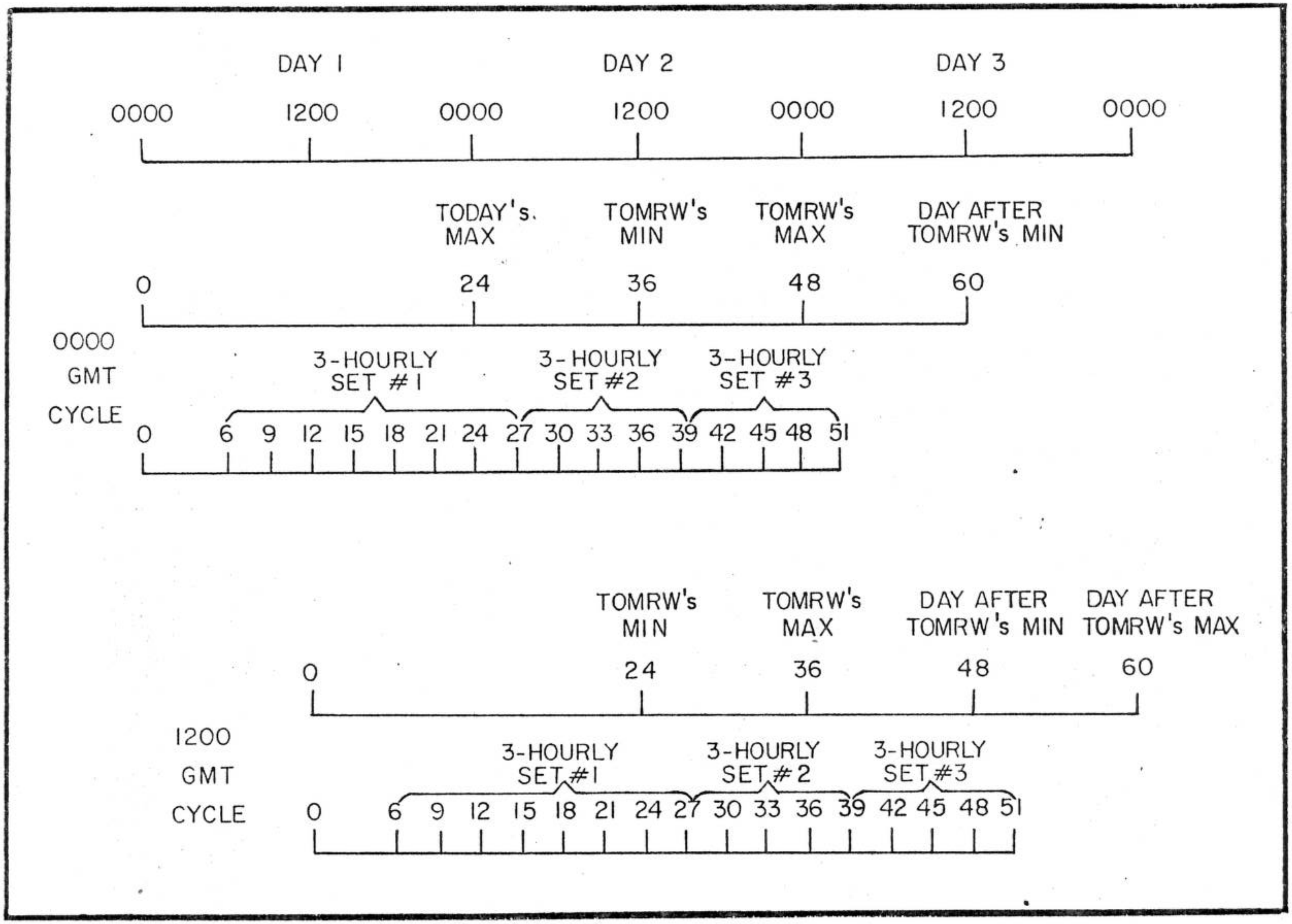

Figure 1. Forecast periods associated with the early guidance temperature prediction equations. During development the predictands were grouped into three sets that each contained 3-hourly temperatures and one max or min. The equations to predict the fourth period max or min were developed separately.

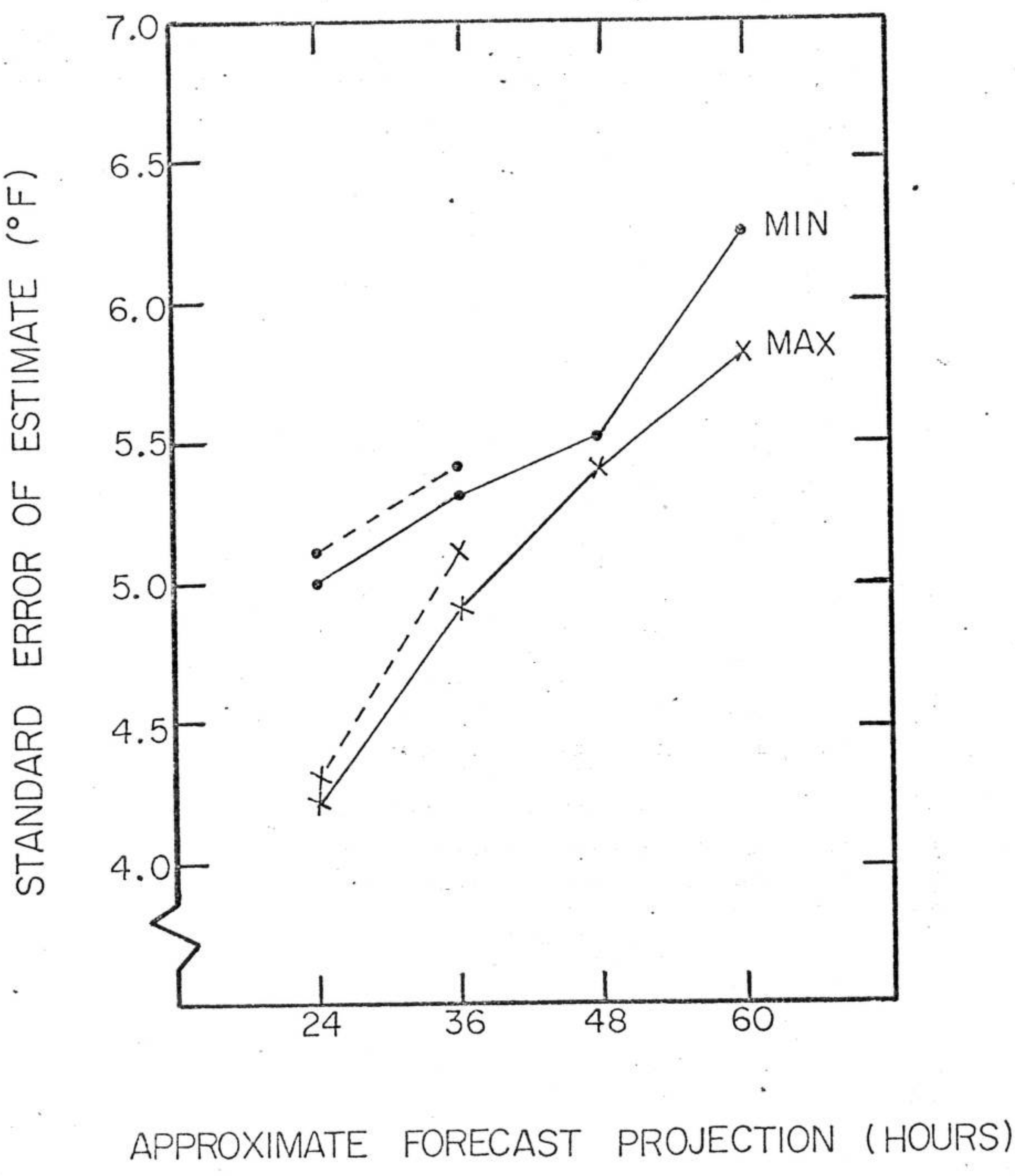

Figure 2. Standard errors of estimate (^{o}F) for the cool season early guidance max (X) and min (●) forecast equations. Values for the first projection are an average of those for the fall and winter seasons. The dashed lines indicate standard errors for the backup equations which do not use surface observations as predictors.

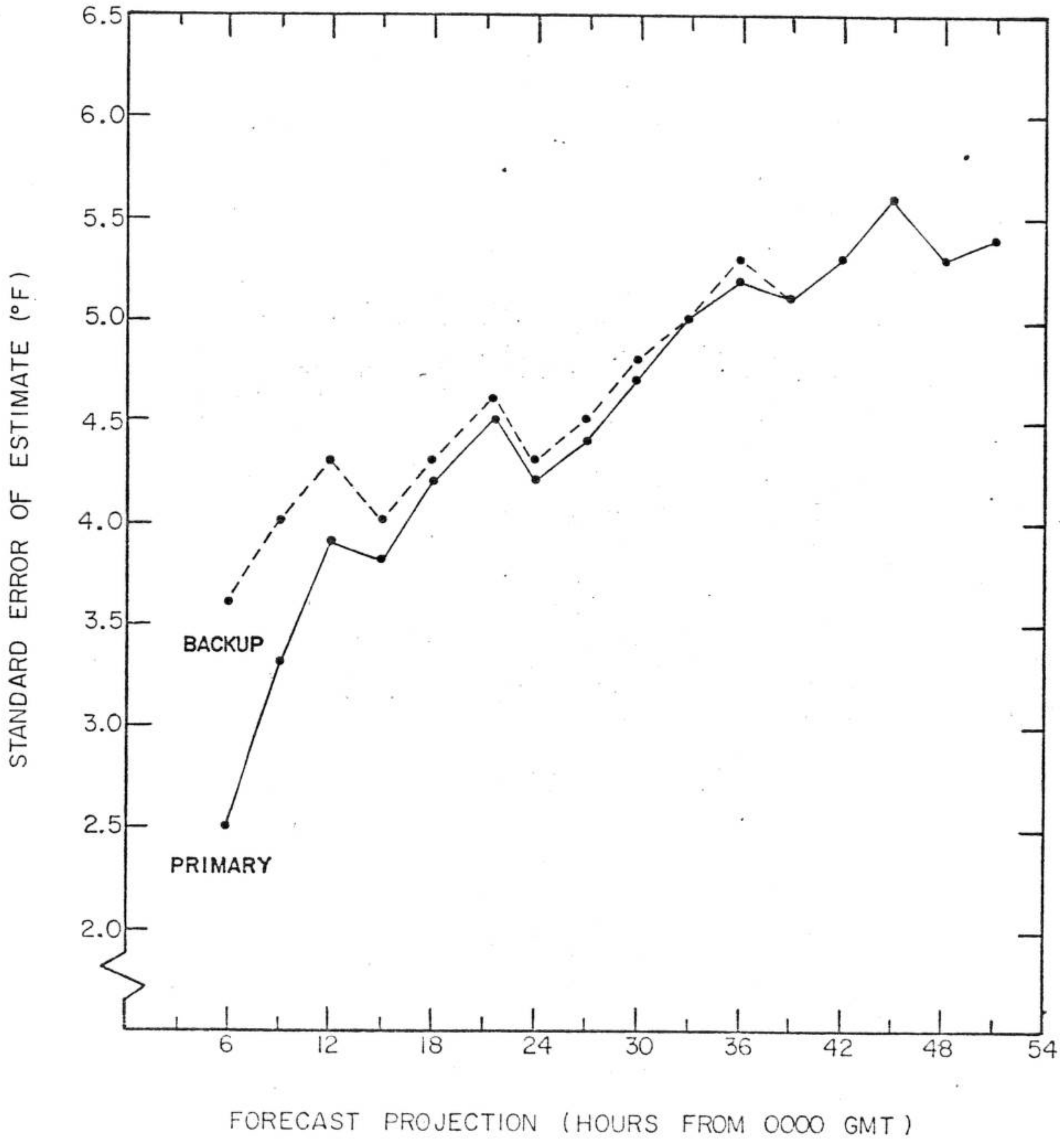

Figure 3-a. Standard errors of estimate (^{o}F) for the cool season 0000 GMT 3-hourly temperature forecast equations. The values for the 6-through 27-h projections are averages of the fall and winter season errors. The dashed lines indicate standard errors for the backup equations which do not use surface observations as predictors.

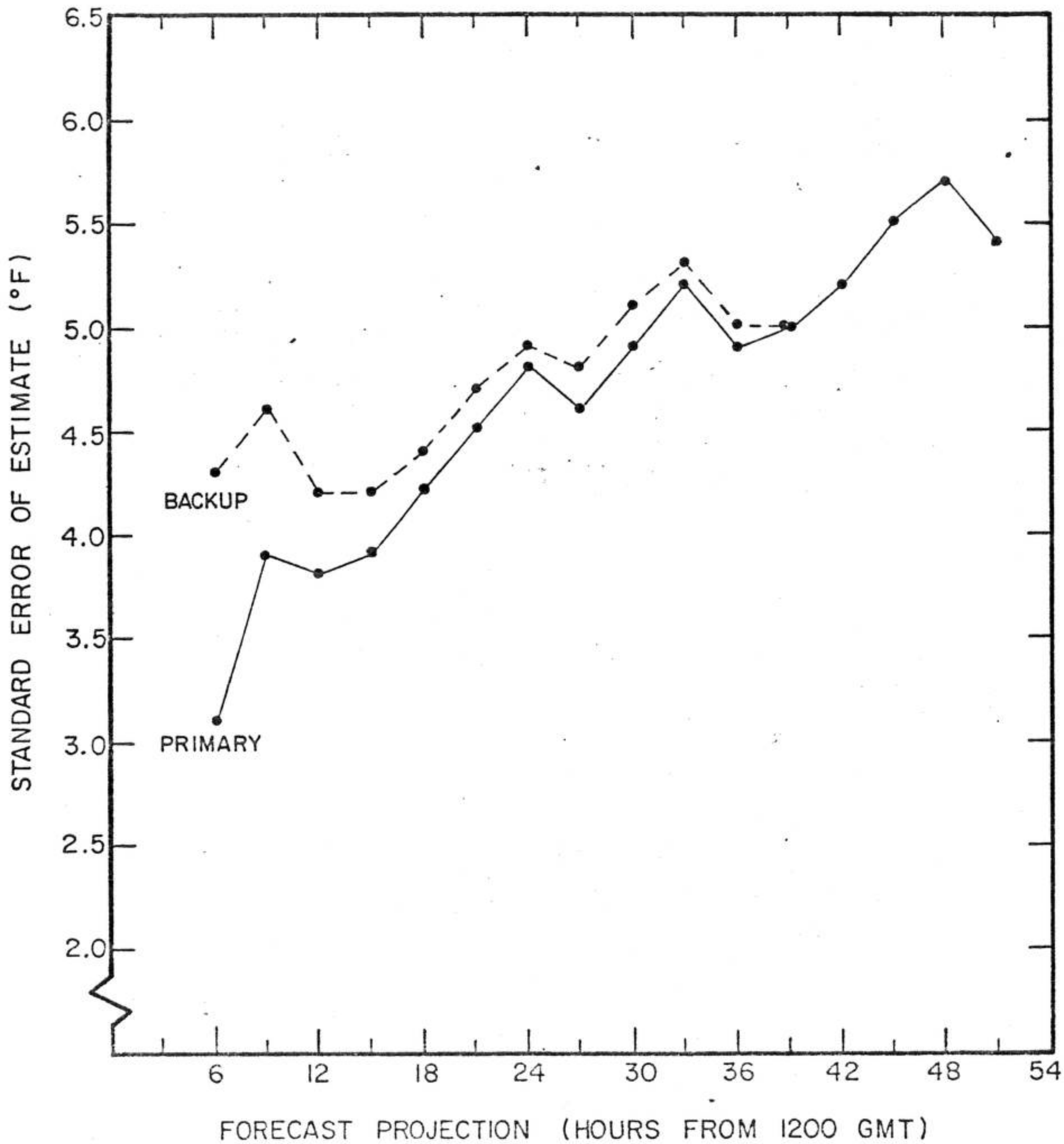

Figure 3-b. Same as Figure 3-a except for 1200 GMT equations.

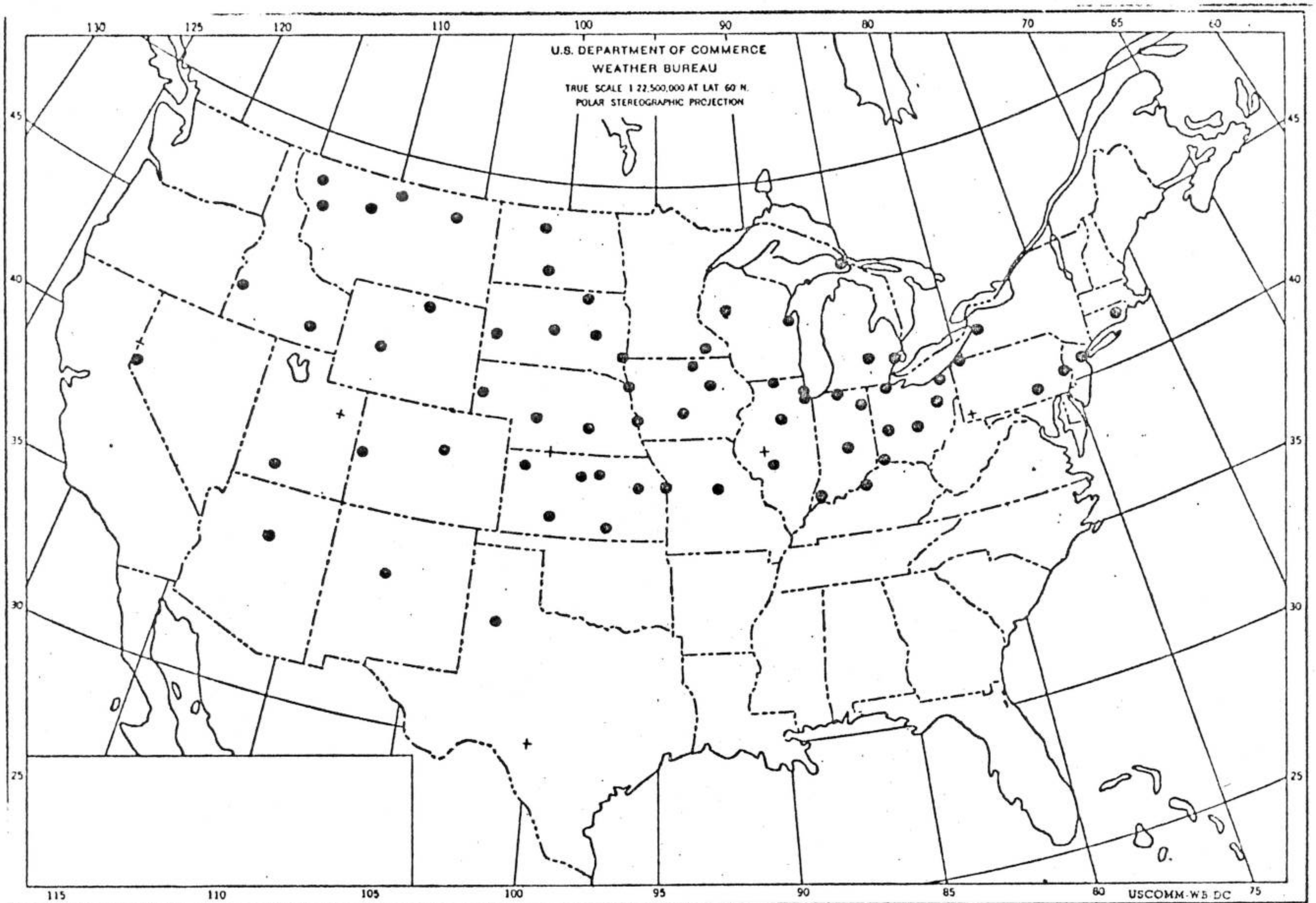

Figure 4. Stations that use observed snow cover (from the previous 1200 GMT report) as a predictor for the winter season 24-h max (0000 GMT cycle).

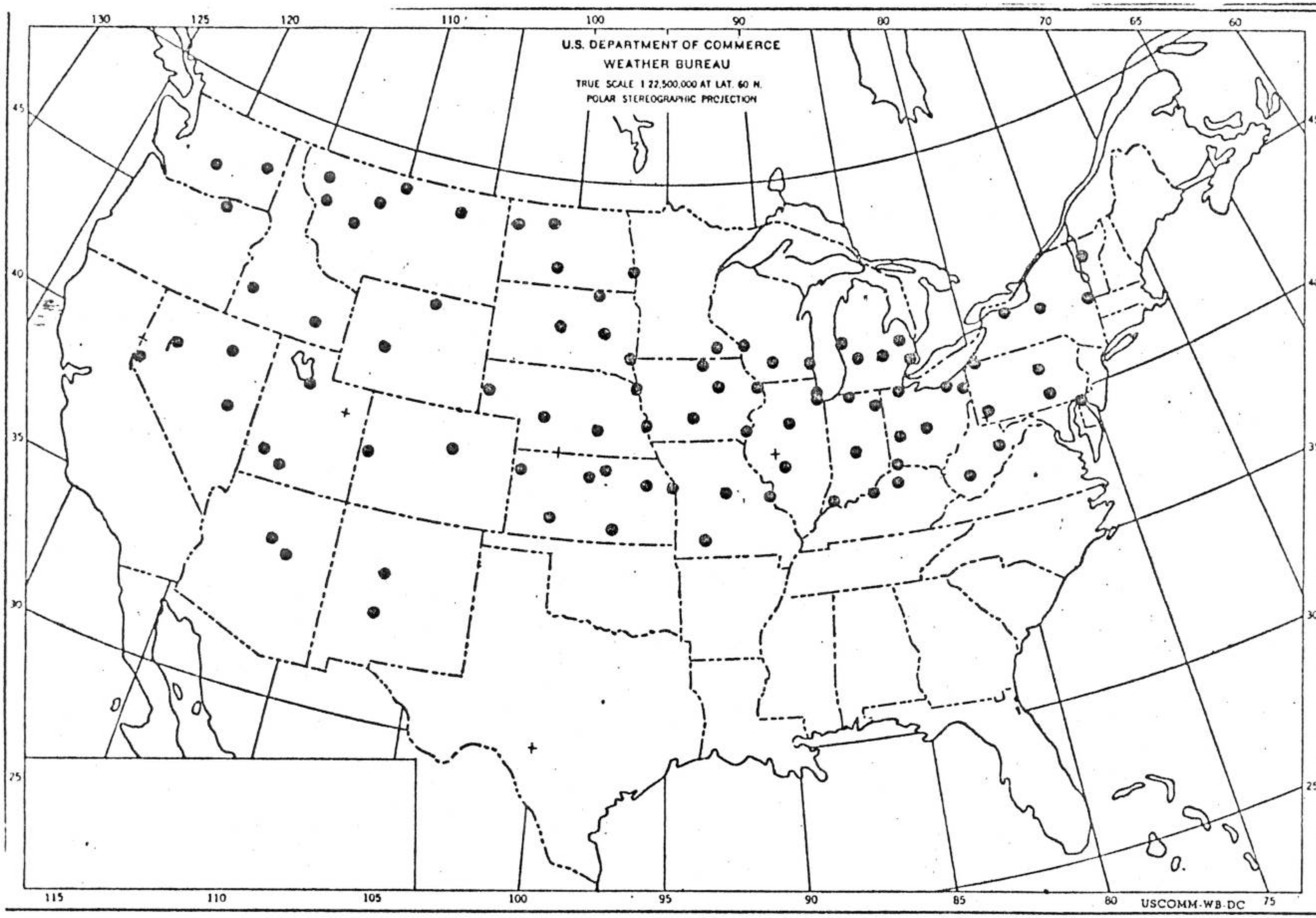

Figure 5. Stations that use observed snow cover (1200 GMT report) as a predictor for the winter season 24-h min (1200 GMT cycle).

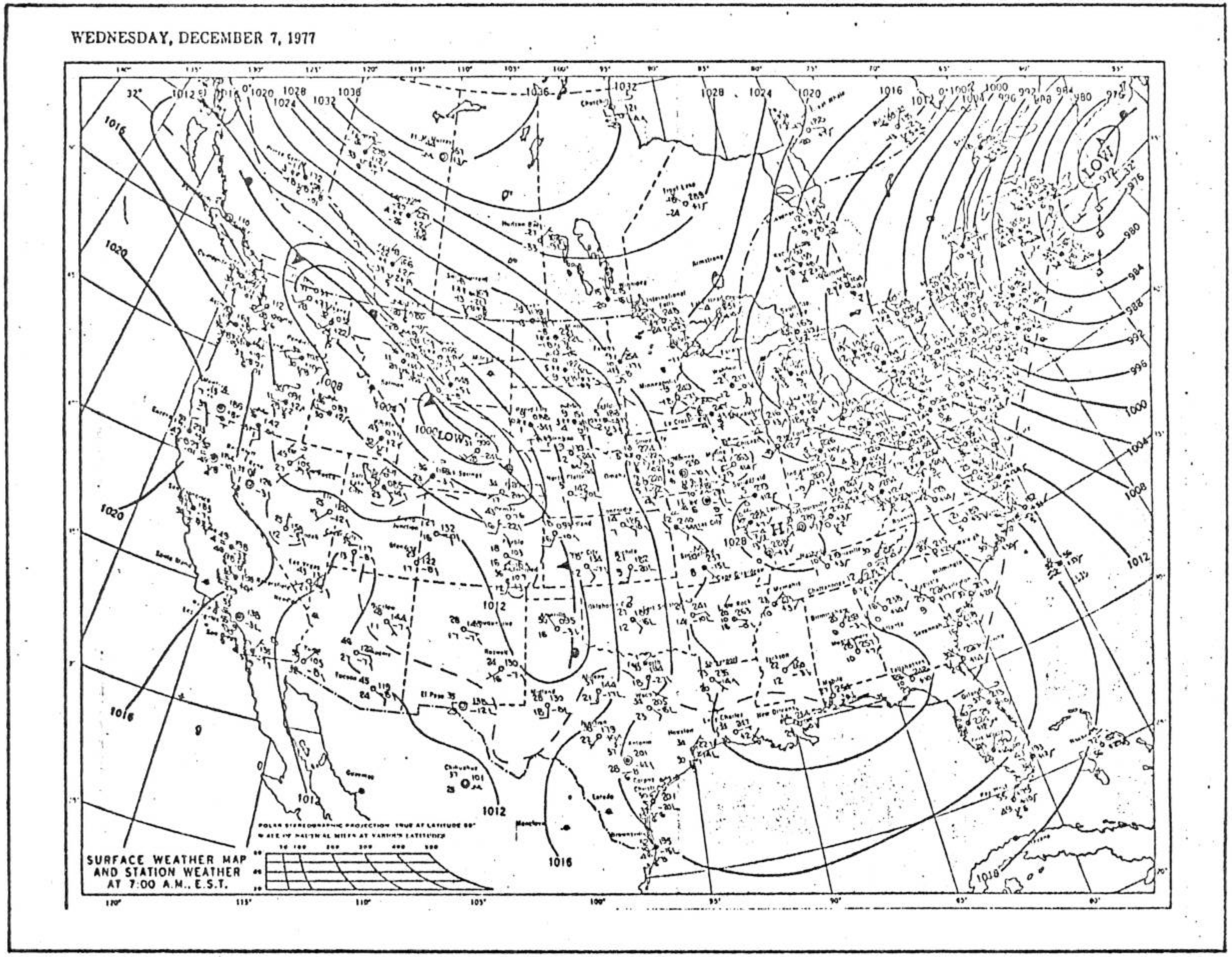

Figure 6. Surface weather map for 1200 GMT, December 7, 1977.

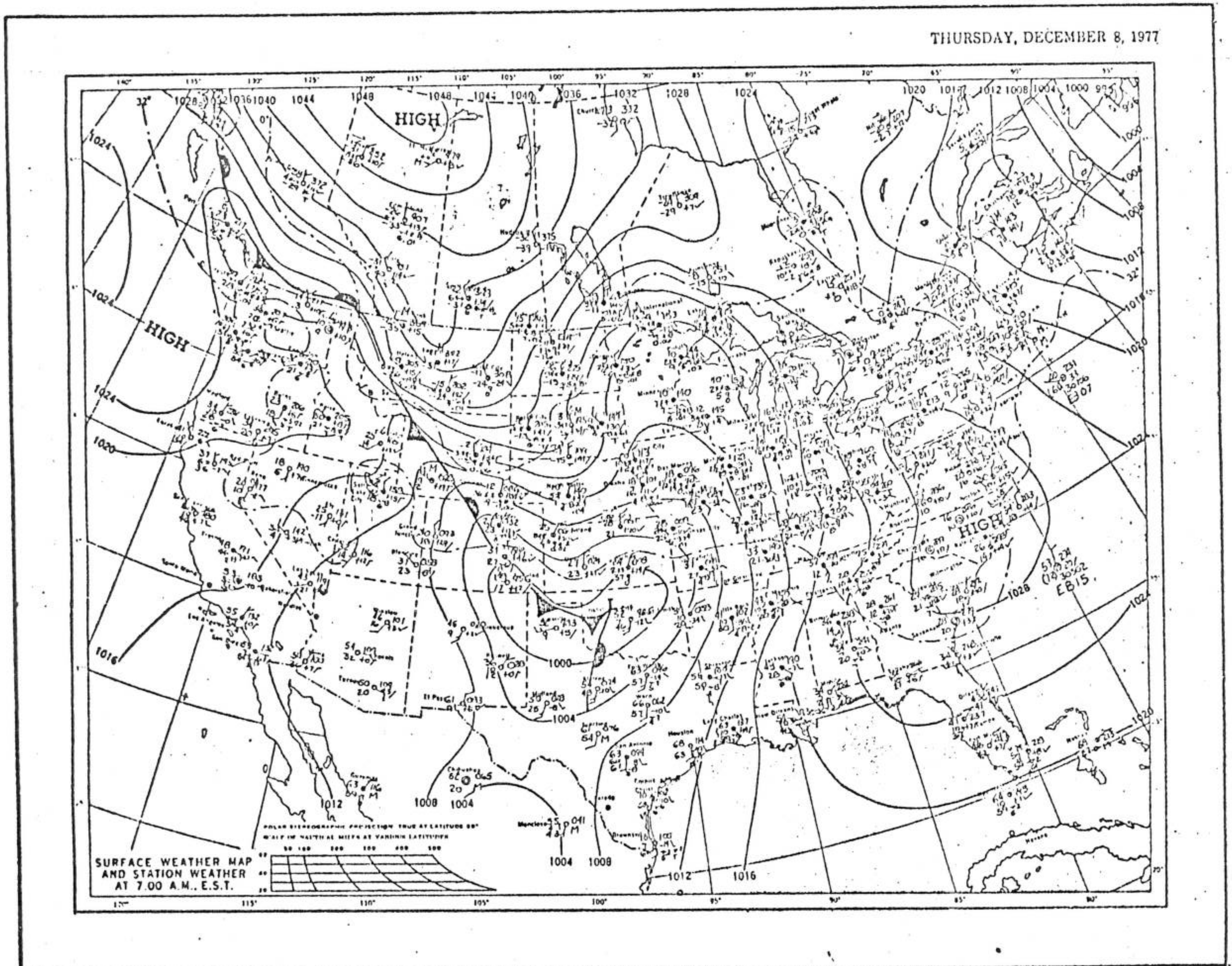

Figure 7. Surface weather map for 1200 GMT, December 8, 1977.

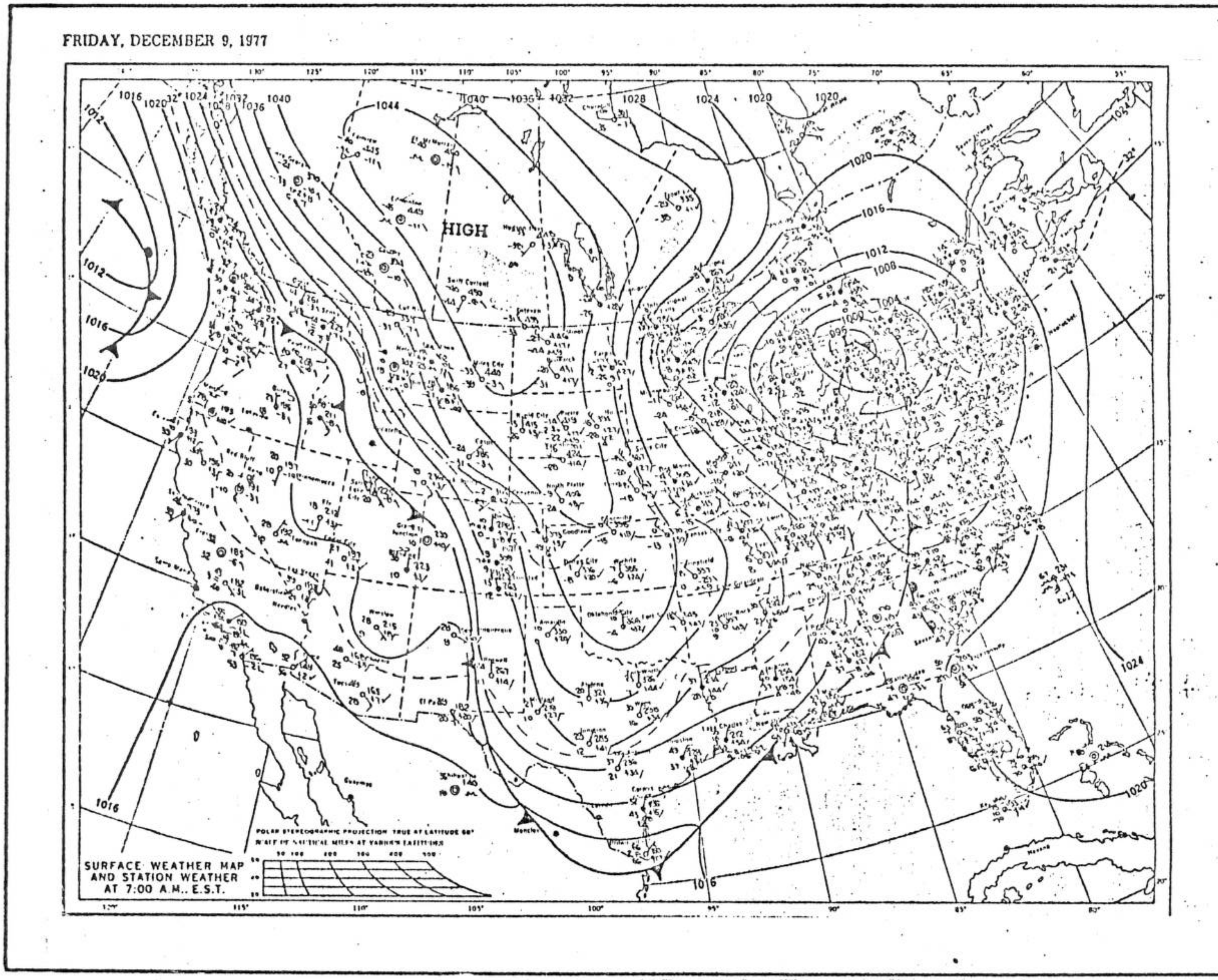

Figure 8. Surface weather map for 1200 GMT, December 9, 1977.